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ON THE ULTRA VIOLET COMPONENT IN ARTIFICIAL LIGHT.

By Louis Bell.

With two Plates

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THE ULTRA VIOLET COMPONENT IN ARTIFICIAL LIGHT.

By Louis Bell.

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Purpose of the Investigation. — The fundamental purpose of this study has been definitely to evaluate the amount of energy given by various artificial illuminants in the ultra violet portion of the spectrum. In particular, beside determining the general proportion of ultra violet rays and their actual amount in each lamp investigated, the writer has determined in absolute measure the ultra violet energy delivered by each light source for unit illuminating value. Assuming that each of the artificial lights studied is to be used to produce a certain given illumination, the amount of ultra violet radiation incidental to that illumination has been set down in absolute terms of ergs per second per sq. c. m. This classification of illuminants, which has not hitherto been made, is important in view of the possible harmful effects of radiation of short wave length which have been repeatedly discussed during the past few years. The amount of such possibly injurious radiation given by any particular lamp is a matter of small importance except as it is correlated with the illuminating power of the lamp, so that one may know to what amount of possibly harmful radiations he is exposed in securing a required degree of illumination.

Nature and extent of Radiations under Suspicion as harmful. — There has been much discussion concerning the effects of radiations of different wave lengths upon the eye. Without going extensively into an examination of the literature, which is very scattered and extensive, or of the physiological facts, some of which the writer now has under careful investigation and which will be reported later, it is sufficient here to say that the investigators of this matter may be divided into somewhat divergent schools. All agree that the extreme ultra violet rays, those of wave length less than 300 $\mu\mu$, which are absorbed by the cornea and so do not penetrate to the inner parts of the eye, produce when in sufficient intensity more or less serious damage to the corneal ephithelium, resulting in acute irritation, always accompanied by conjunctivitis, and sometimes by cloudiness of the cornea and other symptoms which go to make up the complex

injury which has come to be known as *ophthalmia electrica.* It is in effect a superficial sunburn of the eye and is often accompanied by a similar sunburn in the vicinity of the affected eye. Whether this particular sort of effect is produced also by ultra violet rays of slightly greater wave length, say up to 320 $\mu\mu$ or 330 $\mu\mu$, is a matter of some dispute, but most investigators have held this particular region under suspicion on account of the phenomena of snow blindness, which closely resemble those of the so-called *ophthalmia electrica,* and cannot be produced by the extreme ultra violet rays since the solar spectrum owing to atmospheric absorption is extremely weak at and below 300 $\mu\mu$, very near to which point it is wholly cut off. It is, however, fairly rich at 320 to 330 $\mu\mu$, the cutting off by atmospheric absorption being rather sudden, as shown in *a,* Plate **1**.

Now while the cornea cuts off only rays of wave length less than 300 $\mu\mu$ the lens of the human eye ordinarily absorbs the whole ultra violet, it being substantially due to this absorption that we are unable to see beyond the violet. This absorption extends to about wave length 380 $\mu\mu$ and in old persons in whom the lens gets slightly yellow even as far as wave length 420 $\mu\mu$. In early youth there is a very slight transmissibility of the lens in the region 315 to 330 $\mu\mu$ as shown by Hallauer.[1] Now potentially the rays which are absorbed by a medium may produce changes in it and the ultra violet rays up to and including the extreme violet have been reputed by various writers to produce a large variety of lesions, including retinal injury due to the rays which may filter through the lens. The list of reputed dangers is a very long one including erythropsia, color scotomata, cataract and other serious results. The situation from the point of view of the ophthalmologists who seem to be really in fear of ultra violet radiations is well summed up by Schanz and Stockhausen.[2] Other writers like Best [3] and Voege [4] attach relatively little importance to the effect of the ultra violet as such and are inclined to attribute some of the phenomena to over-intense radiation of ordinary light or to causes not connected to radiation at all.

A third group, of which Birch-Hirschfeld [5] is a representative, holds an intermediate view. It should be noted that the permanent

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[1] Klin. Monatsbl. f. Augenheilk., Dec. 1909.
[2] Ztschr. f. Augenheilk., May 1910.
[3] Klin. Monatsbl. f. Augenheilk., May 1909.
[4] Die Ultravioletten Strahlen der modernen kuenstlichen Lichtquellen und ihre augenbliche Gefahr für das Auge. Berl., 1910.
[5] Ztschr. f. Augenheilk., July 1908, and elsewhere.

injuries ascribed to ultra violet rays, like cataract and retinal degeneration, are charged to the radiations running even up to the visible spectrum, while the extreme ultra violet, absorbed by the cornea, produces only superficial lesions generally recovered in a few days.

From the standpoint of the present investigation it did not seem justifiable to attempt to pass without further investigation on the validity of any of the divergent views here noted, but to deal with the radiations of short wave length as a whole, including in the possibly injurious group all those radiations which have been under serious suspicion on clinical evidence by reputable investigators. The line has therefore been drawn between the ordinary lighting radiations and radiations of short wave length in the extreme violet and ultra violet of the spectrum, where the lighting value of the rays is negligible and their actinic value notably high.

Separation of the Ultra Violet from the Visible Spectrum. — Having determined on such a separation of the radiations under grave suspicion of injurious action from the rest of the spectrum, it was next in order to find a suitable screen for making just this division of the spectrum, so that it would be possible to measure the energy in the two portions of the spectrum directly and as a whole, without a resort to the extremely difficult and troublesome measures of the energy in separate spectrum lines, a task of great delicacy when discontinuous have to be compared with continuous spectra. After considerable investigation a suitable medium was found in the so-called Euphos glass. This glass, which has been strongly recommended by Schanz and Stockhausen as eliminating completely all the harmful rays and which was prepared under the direction of one of them, cuts off the ultra violet spectrum with remarkable definiteness while showing relatively little absorption of the general luminous rays.

Plate **1**, *b*, *c*, *d*, shows the nature of this absorption very clearly. Spectrogram *b* of this Plate is the spectrum of the mercury quartz arc put on merely for reference, the group at 365 $\mu\mu$ being at the right of the figure and the brilliant green line exactly in the centre of the plate. Spectrogram *c* shows the spectrum of the magnetite arc which is very rich in the ultra violet and *d* shows the same as absorbed by a Euphos glass screen 2 mm. thick. The exposure in each case was one minute with a rather wide slit and a very brilliant grating. The cut off of the shorter wave lengths by the Euphos glass in the ultra violet is very clean and sudden at wave length 390 $\mu\mu$, practically just at the end of the visible spectrum as seen by the average eye. The

absorption continues slightly on into the violet, gradually fading away until the transmission becomes nearly complete for the bright blue mercury line (435 $\mu\mu$).

In examining *b, c* and *d* of Plate **1** it must be remembered that the second order ultra violet overlaps the first order so that the group near 365 $\mu\mu$ appears in the first order at the extreme right of the figure and in the second order at the extreme left. In *d* of this Plate the arc spectrum fades off on the left, not from absorption but from the weakening of the photographic action. The Euphos glass is extremely transparent to the radiations throughout all except the extreme violet of the visible spectrum, and well into the infra red, as will hereafter be seen. The results here obtained for its absorption of the ultra violet are altogether parallel with those shown in the paper by Schanz and Stockhausen [6] and also by Hallauer.[7] The Euphos glass thus enables a particularly clean partition of the visible spectrum from the ultra violet and extreme violet to be made.

If it were possible to obtain an equally good absorbent for separating the infra red from the visible spectrum radiometric measurements of efficiency would be greatly facilitated. It should here be noted that Euphos glass appears in various shades and some imitations of it are now upon the market, so that a sample of such glass should be tested in the spectrograph before use for such a purpose as the present, inasmuch as in some of the shades the cut-off of the ultra violet is much less sharp and complete. The sample here used was the original No. 1, 2 mm. thick.

Method of Investigation. — The method taken for the evaluation was the familiar one of measuring the radiation directly by means of a thermopile connected with a sensitive galvanometer in a manner familiar in recent experiments on the efficiency of illuminants in the visible spectrum, e. g., Lux,[8] Féry.[9] The thermopile was chosen as the radiometric instrument merely as a matter of convenience. The instrument actually used was a Rubens linear thermopile, having 20 constantin-iron couples with a total resistance of 4.6 ohms. It was mounted as shown in Figure 1, in a vacuum tube with a quartz window immediately in front of the couples. The inner body of the instrument, containing the couples, was taken out of its original mounting and set up in a tube about 37 mm. in diameter, through the upper end of which was sealed a pair of leading-in wires.

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[6] Zts. f. Augenheilk., May 1910, Table VII, figure 3.
[7] Archiv. of Ophthal., Jan. 1910, Plate II, figure 3.
[8] Zts. f. Beleuchtungswesen, Heft 16, 1 p. 36, 1907.
[9] Bull. Soc. Franc. de Physique, p. 148, 1908.

These were firmly clamped in the binding posts of the instrument by working through the side tube attached for the reception of the quartz window. The thermopile was then pushed up exactly opposite the side tube and wedged in place with cork and cotton wool attached with shellac. The end of the side tube was flanged out and ground flat for the fitting of the quartz window and after the shellac had dried out thoroughly the window was fastened in place and the lower end of the tube drawn out for the attachment of the pump. The tube was pumped to the high vacuum usual in an X-ray tube, and was then sealed. It was mounted as shown in a block of wood to which was secured the disconnecting terminal, reached by a long handled plug,

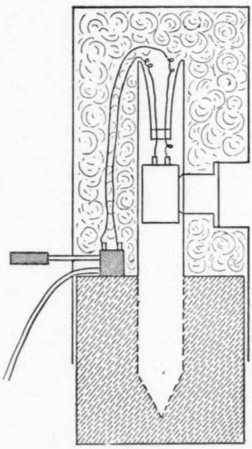

FIGURE 1. Vacuum thermopile.

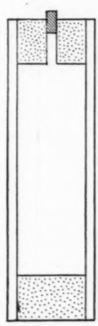

FIGURE 2. Quartz cell.

and the whole was then surrounded by a pasteboard case having a hole just opposite the quartz window, and packed full with loose cotton wool. The galvanometer was of the D'Arsonval type, having a sensibility of 2×10^{-8} ampere per mm. scale deflection. Its period for the attainment of a complete deflection, was, under the ordinary conditions of its use, 1 minute.

The galvanometer deflections were read by a scale and telescope, the scale being a special one bent to 1.5 meters radius. The thermopile indications were calibrated in absolute measure by observations

on the radiation of a standard incandescent lamp supplied by the Bureau of Standards. After applying the proper correction for stray thermal losses and spherical reduction factor and reducing the readings as taken to the standard distance of 50 cm. employed throughout this investigation, the constant of the thermopile galvanometer system was found to be 1 mm. = 1 scale division = 35.3 ergs per second per square cm. By this constant the observed deviations were reduced to absolute dynamical measure.

As a matter of convenience and to establish an approximate ratio between the ultra violet radiation from the various sources studied and the radiation in the visible spectrum, an absorption cell which

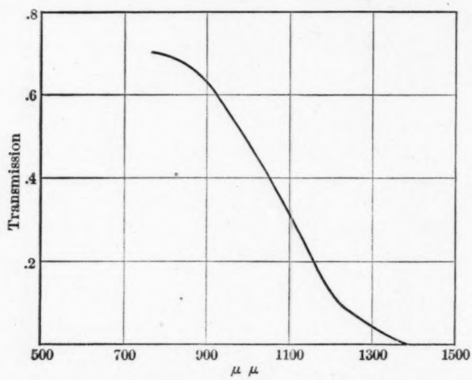

FIGURE 3. Absorption curve of water.

eliminated nearly all the infra red was kept in front of the thermopile window. This cell, Figure 2, was of glass, ground flat and exactly 1 cm. thick, 44 mm. external diameter and 35 mm. internal diameter. The glass ring was provided with a hole for filling and was closed by two quartz plates cut across the axis, each 2.25 mm. thick and 44 mm. diameter. These were fastened with hard shellac to the glass cell, and the cell in use was filled with distilled water. The absorption of a layer of distilled water of this thickness is shown in Figure 3 taken from Nichols's experiments.[10] Quartz has no material absorption in the part of the infra red spectrum transmitted and neither quartz nor

[10] Nichols, Physical Review, Vol. 1, p. 1.

distilled water in this thickness has any material absorption in even the extreme ultra violet up to the limit investigated.

The use of this cell therefore could produce no sensible effect on the accuracy of the ultra violet measurements, while it did serve the extremely useful purpose of limiting the total amount of energy to be measured and of eliminating any difficulties that might arise owing to absorption in the further part of the infra red, all the absorbing media incidentally used being, as compared with water, practically entirely transparent to all the radiations that got through the water cell. It would have been convenient if some substance cutting off the infra red sharply at 750 $\mu\mu$ or 800 $\mu\mu$ had been available. Unfortunately, there is no such substance, so far as has yet been discovered, the very few substances less transparent than water in the region 800 to 1300 $\mu\mu$ being useless for the purpose of this investigation on account of opacity in the ultra violet and generally in the visible spectrum as well. Iron ammonium alum used by Lux (loc. cit.) and the copper salts used by Féry (loc. cit.) are open to this objection and the same is true of all the otherwise useful and promising substances discussed in the very thorough and valuable researches of Coblentz.[11]

In some of the experiments a second similar quartz cell was used, particularly in work on arc lamps. In this case the Euphos glass used to cut out the ultra violet portion of the spectrum was permanently affixed to one of these cells and either the plain quartz cell or the Euphos-quartz cell was thrust into the beam so as quickly to get differential readings. In order to avoid the somewhat large correction due to reflection of energy which would have been produced by the introduction of a plain slip of Euphos glass to cut out the ultra violet the following expedient was adopted.

The Euphos glass was attached to the surface of the quartz cell by spring clips with the addition of a thin capillary film of pure glycerine between the quartz and glass surface. Glycerine is immensely transparent to all radiations, including the extreme ultra violet, to which Canada balsam and gelatine are quite opaque. Its index of refraction, 1.47 for D, is sufficiently near that for quartz and the various glasses to reduce the loss of light at the surfaces to an entirely negligible amount. As the Euphos has a slightly less index of refraction than quartz, there was a minute residual gain in the total transmission of the system when the Euphos glass was added, in the right direction to compensate for the minute losses by absorption in the glycerine film.

[11] Bull. Bureau of Standards, Vol. 2, p. 619.

As a check on the possible magnitude of this virtual absorption by the glycerine film readings were taken on a tungsten lamp through the quartz cell alone, and through the quartz cell plus a disc of optical crown glass 2 mm. thick secured with glycerine in the ordinary manner. The absorption of this crown glass is shown in Plate 1, *e, f, g,* in which *e* is the spectrogram of the quartz arc taken with a wide slit and 2 minutes exposure, *f* the spectrogram through the crown glass in question, and *g* through the Euphos glass. In spite of the fact that there is a slight absorption by the crown glass in the region near 300 $\mu\mu$, the addition of the crown glass and glycerine film reduced the galvanometer deflection by barely 0.5 %, an amount scarcely outside the errors of observation. The energy cut off from the spectrum of a tungsten lamp by the crown glass would be of course very small, but perhaps not negligible, since as Schanz and Stockhausen have shown (loc. cit. table VIII, figure 6) the tungsten lamp spectrum goes quite down to 300 $\mu\mu$ in sufficient strength to give a clear photographic effect. At all events it is evident that the use of the glycerine film involves no material errors.

In the ordinary experimentation in using steady sources, sets of readings were taken alternately with and without the Euphos glass, the glass being either added to the clear cell with the glycerine film, or removed and the film quickly washed away with distilled water. With sources which give trouble from unsteadiness the second quartz cell was brought into play as previously mentioned. Aside from a slight drifting of the zero point, which is generally observable in measurements with a thermopile, the method adopted worked very smoothly. The drift, however, was usually small and slow and satisfactorily taken care of by a time correction. With proper attention to this, the readings, although necessarily slow, were nearly as consistent as would be found in ordinary photometric measurements. The following string of deflections forming a single group of 5 readings is typical of those obtained under ordinary conditions.

Scale readings from bare quartz lamp through quartz cell only.

	cm.
	36.17
	36.10
	36.27
	36.36
	36.16
Av. =	36.21

The mean departure of a single reading from the average here given is slightly less than $\frac{1}{4}\%$, so that the errors of observation, of which this is a fair sample, showed that the thermopile observations are about as reliable as those with a photometer. Some preliminary experiments made on Euphos and other glasses showed that the transmission of the Euphoa glass aside from its absorption in the violet and ultra violet was exceptionally high for such rays as got through the layer of distilled water. In fact the total transmission of energy with Euphos glass was greater than with the ordinary samples of clear glass and was only exceeded by a single sample of optical crown which showed extraordinary transparency to all these radiations, so great that the losses were practically only those chargeable to actual reflection at the surfaces.

Measurements on various Illuminants. — With these preliminaries the apparatus was set up permanently and work begun on commercial illuminants. Readings of current and voltage on the electric lamps were taken by Weston instruments freshly calibrated, and the quantity readings on the gas lamps tested were obtained from a newly adjusted standard meter.

100 Watt Tungsten.— The first source of light investigated was an ordinary 100 watt tungsten lamp, taking actually .951 amperes at 113 volts, i. e. 103.3 watts, and giving 79.4 c. p. in the direction of the thermopile. With this lamp the mean difference of deflection due to energy cut off by the Euphos glass was 1.9 cm. The ultra violet energy cut off, including such losses in the extreme violet as are indicated by Plate **1**, *d*, was 6% of the total energy transmitted by the quartz cell.

100 Watt Gem. — The second source studied was an ordinary 100 watt Gem lamp, taking 100 watts at 114 volts and giving in the marked direction 39.25 c. p. This lamp of course gave a spectrum relatively weak in the ultra violet, but as will be seen from its spectrogram in Plate **2**, *b*, the ultra violet region down to wave length 330 $\mu\mu$ is by no means negligible. The total differential deflection due to the ultra violet was in this case only 0.61 cm., 2.6% of the total deflection. These readings confirm the extraordinarily small absorption of Euphos glass throughout the longer wave lengths, since the transmission observed with the known cut off of a very perceptible amount in the ultra violet, leaves no room for any material selective or general absorption elsewhere.

It should here be noted that while quartz transmits with extraordinary freedom, so far as absorption is concerned, all rays which are

allowed to pass by a cm. thickness of distilled water, it still exercises a slight selective action by reflection. The index of refraction of quartz for the longer wave lengths of the visible spectrum is 1.54, while for rays in the further ultra violet this figure rises to about 1.6, hence in accordance with Fresnel's formula $\left(\frac{n-1}{n+1}\right)^2$ there is a small amount of selective stopping of the ultra violet rays by reflection. This occurs both at the quartz water cell and at the quartz window in front of the thermopile so that the total selective effect is proportional to the fourth power of the difference due to the change in the index of refraction for a single surface of transmission. This difference amounts to approximately 2% as between the red rays and the further part of the ultra violet. The result is to cause a slight under estimation of the ultra violet. No account has been taken in any of these experiments of this very small and troublesome correction, which amounts in ordinary cases to only a small fraction of 1% of the total ultra violet. The existence of the effect should, however, be noted as it has a tendency toward causing a slight under estimate rather than an over estimate of the ultra violet component.

Cooper Hewitt Tube. — The next source investigated was the Cooper Hewitt tube. One of the ordinary commercial 22 inch tubes was used, the particular tube having previously been used in another research and very carefully photometered. A section of this tube, giving 100 c. p., was screened off so that the length might be so reduced that the energy from the whole section taken could fall freely upon the thermopile without causing a material angular error or forcing one to depart widely from the standard distance of 0.5 meter. The horizontal radiation normal to the tube was of course taken, the reflector being removed. The corrected deflection due to the ultra violet amounted to 1.64 cm. which corresponded to 41.7% of the total energy passing through the quartz cell. The lamp was singularly steady and easy to work with, with the exception of producing an inconveniently small total deflection. The result, however, can be regarded as fairly precise in spite of the small magnitude, the mean deviation of a single reading amounting to barely over .5% in the total deflection. In this lamp the ultra violet energy is nearly all between 365 $\mu\mu$ and the visible spectrum, the extreme ultra violet being entirely cut off by the glass of the tube and the few lines of wave length between 365 and 300 $\mu\mu$ being reduced by the absorption to very feeble intensity. The total deflection produced by this lamp, of which the portion exposed radiated 100 c. p., was only 17% of the deflection given by the Gem lamp of the previous experiment, which gave less than 40 c. p.

Quartz Mercury Lamp. — Following the examination of the ordinary glass Copper Hewitt tube, the next source investigated was the quartz mercury lamp. Two tubes were available, each of the ordinary commercial 220 volt type rated at 3.5 amperes. One of these tubes, which is here referred to as the old mercury lamp, was made by the French Cooper-Hewitt Company and had been already used for experimental purposes for about a year and had seen rather hard service, having often been worked above its rated amperage. The second lamp was entirely new, made in the Cooper-Hewitt factory in this country and was not at any time worked above its rating. The spectrum of the quartz lamp is extremely rich in certain portions of the ultra violet, particularly in rays of wave length less than 300 $\mu\mu$. It is well shown in Spectrum *e* of Plate **1**. The brilliant lines in this spectrum, counting from the violet, have wave lengths as follows: —

4077.84	2967.27
4046.55	2925.38
3983.96	2893.60
3906.47	2752.80
3663.27	2698.88
3662.88	2655.14
3654.83	2653.70
3650.14	2652.07
3341.48	2536.52
3131.84	2483.87
3131.56	2482.76
3125.67	2482.07
3027.49	2399.81
3025.61	2399.43
3023.43	2378.39
3021.50	2302.65

The wave lengths here are taken at the value assigned by Stiles [12] in A. u. It will be observed that a number of the lines are associated in close groups which with small dispersion mass into heavy lines. The relative intensity of the lines, as is well known, shifts considerably with the degree of excitation of the tube, so that the relative intensities given by Stiles do not agree with the spectrograms taken from the quartz arc for the same reason that Stiles' arc and spark intensities do not agree. The quartz arc spectrum resembles Stiles' arc spectrum much more closely than it does the spark spectrum.

[12] Astrophysical Journ., Vol. XXX, p. 48.

In particular the quartz arc spectrum displays a very striking gap between wave length 334.14 $\mu\mu$ and the double line at wave length 313.1 $\mu\mu$. Save for the very faint haze of continuous spectrum that characterizes the radiation from the quartz tube this part of the spectrum is blank. Indeed the line 334.14 $\mu\mu$ itself is far from strong relatively to those in the further part of the ultra violet and there is very little effect of radiation between wave length 313.1 $\mu\mu$ and 365.2 $\mu\mu$. This gap is of some significance in interpreting the results of bactericidal experiments, since any failure of bactericidal action in the region between wave length 350 $\mu\mu$ and wave length 313 $\mu\mu$ observed in working with the quartz lamp may be due to the absence of any strong radiation in this region as well as to lack of specific bactericidal power in rays of this particular wave length if they existed.

In the radiometric investigations on the old quartz lamp it was run at 3.7 amperes and about 80 volts, an average of about 260 watts, without an external globe. Under these circumstances the corrected deflection due to the total ultra violet was 16.7 cm. The deflections were not quite so steady as in the case of the ordinary Cooper Hewitt tube, but still the average departure of a single reading was within 1%. After the deflection due to the total ultra violet was determined another set of readings was taken with the bare lamp and quartz cell and then with the Euphos glass replaced by the crown glass of which the absorption spectrum is shown at *f*, Plate 1.

This glass in effect cuts off substantially the whole of the extreme ultra violet spectrum, letting pass in practically undiminished strength only the lines of greater wave length than 300 $\mu\mu$. This separation is of some importance with respect to the bactericidal power of the lamp in water purification and similar work. The result was to show that the transmission of the crown glass was 54.7 % of the transmission found for the Euphos glass. In other words, nearly one half of the total ultra violet energy in this lamp was of wave length below 300 $\mu\mu$. Of the remaining half the spectrum shows, as just indicated, that by all odds the larger part lies between 365 $\mu\mu$ and the visible spectrum.

The new quartz lamp without its globe was then tested, the input in this case being 350 watts. The ultra violet output was greater than in the old tube, the total deflection reduced to the standard distance rising to 32.1 cm. In this case 65.1 % of the energy transmitted by the quartz water cell was cut off by the Euphos glass. Following up the radiometric measurement further, the Euphos glass was replaced by the light crown glass as before with the result of showing that substantially one half, 49.9 %, of the total ultra violet

was cut off by the crown glass and hence substantially this proportion was of wave length less than 300 $\mu\mu$.

In running quartz lamps without their globes, as was done in these experiments, the energy output is considerably diminished by the cooling of the tube and the light-giving properties of the lamp are very much reduced. Both the old and the new quartz lamps herein noted were photometered. The lamps were compared against a tungsten secondary standard by means of a Simmance-Abady flicker photometer. The c. p. normal to the length of the tube and in a horizontal direction, was for the old quartz lamp 415, for the new quartz lamp 348, in each case without any enclosing globe. Both lamps were very steady and easy to work with, both on the photometer bar and with the thermopile.

Finally the new quartz lamp was fitted with its regular diffusing globe and tested with the thermopile. In working with the globe the tube operated at a higher temperature and far more intensively, the wattage rising to 460. With the Euphos glass in, the total change in deflection amounted to only 3.7 cm. although the lamp tested on the photometer as in the previous case reached 820 c. p. in the horizontal direction. In percentage the amount of energy cut off by the Euphos glass was 42.5. These figures plainly indicate that the globe absorbed the further ultra violet very strongly, more strongly than the crown glass already referred to. In fact the deflection due to the ultra violet energy which passed through the globe of the lamp was extraordinarily small with respect to the c. p. of the source, very much smaller than in the case of any other illuminant investigated. Without the globe the quartz arc is a very powerful source of radiation in the extreme ultra violet, below wave length 300 $\mu\mu$. With its ordinary globe on, all this energy in the extreme ultra violet is cut off and the small remaining amount, mostly in that part of the ultra violet nearest the visible spectrum, becomes quite insignificant.

The Welsbach Mantle.— At this point study of the radiation from the Welsbach light was taken up. The particular form used was a Graetzin street lamp with a single large inverted mantle fitted with a clear glass globe, which obviously eliminated whatever of extreme ultra violet might be present. This burner took 6.4 feet of gas per hour at 3 inches pressure and gave 75 c. p. in the horizontal direction. Its total deflection was slightly greater than that produced by the quartz lamp with its globe tested immediately before. The addition of the Euphos glass cut down the deflection by .924 c. m., an amount equivalent to the absorption of 8.4 % of the total radiation recorded. The

lamp proved fairly easy to work with in point of steadiness and the average variation of a single deflection from the mean was still less than 1 %.

Acetylene Flame. — Following the trial of the Graetzin lamp a series of measurements was made on an acetylene flame fed from a Prestolite tank. This flame gave on the photometer in the direction of measurement 27.35 c. p. and its change in deflection on interposition of the Euphos was .524 cm., corresponding to a cut off of 4.5 % of the total energy. It proved very amenable to measurements and was quite as steady and easy to work with as the mantle burner previously used. The spectrum of the acetylene flame reaches well down into the ultra violet as shown by Schanz and Stockhausen.[13] It reaches, in fact, approximately wave length 310 $\mu\mu$, but the further portion of the spectrum is comparatively weak. The spectrum of the Welsbach mantle with a clear globe, given by the same authorities (loc. cit.), is cut off at about wave length 320 $\mu\mu$, but is notably bright in the part of the ultra violet toward the visible spectrum. These results are fully checked by the spectrograms taken of the particular burners here indicated.

The Carbon Electric Arc. — Next in order the various arc lamps were taken up for investigation, beginning with the arc between carbon electrodes. On account of the relative instability of the arcs the method of experimentation was modified. A second quartz cell similar to the one already in use was constructed and filled with distilled water. The ratio of the absorption between this new cell and the old cell was then determined. From a slight difference in thickness or in polish of the quartz plates the new cell was found to give about 1% more absorption than the original quartz cell and a correction for this difference was introduced in the subsequent measurements. The two quartz cells were mounted in recesses in a sliding screen so that either could be brought quickly in front of the thermopile window. The Euphos glass screen was then mounted with a glycerine film on one of the quartz cells so that the cells with and without the Euphos could be rapidly interchanged in the beam from the lamp under test and the absorption thus determined without having to depend on the constancy of the lamp for any considerable time.

The times of observation were regulated by means of a stop watch so that a time correction for shift of zero could be readily made, and

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[13] Zts. f. Augenheilk., V. XXXIII, plate 8.

by taking several preliminary swings, so as to give the thermopile chance to settle into a steady state, the rate of shift of zero was kept pretty steadily and the corrections were easily applied. It was also necessary to photometer the arcs in the actual condition in which they were under test. To this end the apparatus was set up as shown in Figure 4. Here A is the arc lamp, B the thermopile, C the galvanometer, D the telescope and scale, E an adjustable rotating sector disc just in front of the arc, F the quartz cells in their sliding screen in front of the thermopile window, G a silvered plate glass mirror which could be quickly interposed in the beam between the arc and

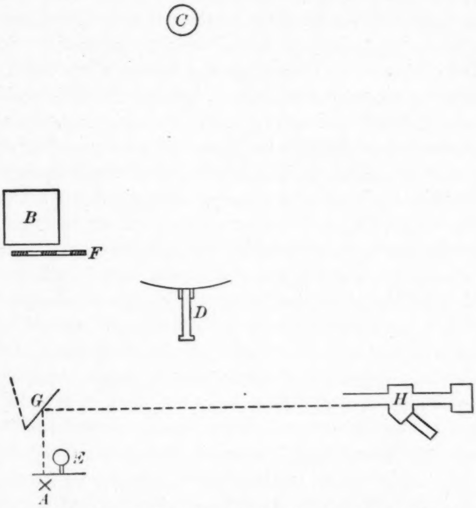

FIGURE 4. Arrangement of radiometric apparatus.

the thermopile so as to deflect the rays into the portable photometer H, set up on the other side of the photometer room. The coefficient of reflection of the mirror had previously been many times determined as the mirror had been in use for photometric work. The photometer was ready for use at any time simply by closing the switch on the standard lamp. When in course of a series of thermopile measurements it was desired to test the c. p. of the lamp the disc was started, the mirror swung into place and readings were then taken on the portable photometer.

The carbon arc was first attacked and it proved to be a difficult subject for investigation. The particular lamp used was of the enclosed type, having the globe fitted with a short side tube and a quartz window so as to keep the arc as steady as possible without losing the ultra violet. To the same end it was found desirable to adjust a magnet behind the arc so as to keep it burning on the side of the carbons next the thermopile instead of wandering round and round the carbons in the usual manner.

The arc thus operated gave a prodigious amount of ultra violet radiation, showing a continuous spectrum far down into the ultra violet and the three enormously intensive carbon bands usually ascribed to cyanogen, one of them in the extreme violet and the other two near wave lengths 380 $\mu\mu$ and 360 $\mu\mu$ respectively. Reduced to the standard distance the deflection due to the ultra violet cut off by the Euphos glass amounted to 74 cm., being 30 % of the whole energy which passed through the quartz cell. It has, of course, been long known that the naked electric arc gives off very powerful ultra violet radiations and its effect in the production of ophthalmia electrica has been known for more than half a century, but in this case the extent of the ultra violet activity was somewhat unexpected.

It was undoubtedly considerably enhanced by the intensive cyanogen bands as regards that portion of the radiation lying near the visible spectrum, but on the other hand the extreme ultra violet, wave length 300 $\mu\mu$ and less, is unquestionably stronger in the case of an open arc than in the enclosed arc on account of the very intense continuous spectrum emitted from the crater, which is much lessened when the arc is enclosed. No separation between these parts of the ultra violet was attempted with the lamp under consideration since its unsteadiness was a constant source of annoyance and the ordinary variations of independent readings from the mean amounted to 5 or 6 %. It was sufficiently evident, however, that a powerful enclosed arc in a globe which permits all the radiations to pass is an enormously powerful source of ultra violet light. The carbon arc, however, is rapidly passing out of general use so that attention was next directed to the luminous arc.

Magnetite Arcs. — The magnetite arc is one of the commonest and most generally useful outdoor illuminants. It gives a very intense nearly white light due almost wholly to the arc stream itself. The spectrum of this, the active electrode being composed almost wholly of the oxides of iron and titanium, is immensely complicated, containing thousands of bright lines so closely packed as almost to obtain

the effect of a continuous spectrum. The actual character of the spectrum photographed with a fairly wide slit, is shown in Plate **2**, *d*. Here, with the quartz arc spectrum for reference at *a* is shown the radiation from the magnetite arc through a quartz window and below it the spectrum of the same arc taken through its ordinary globe. A quartz window was used merely to insure steadiness of the light, which would have been lost by taking off the globe. A glance shows that this spectrum is exceedingly rich in powerful lines all through the ultra violet clear down to wave length 230 $\mu\mu$. The glass globe cuts off the spectrum quite sharply near wave length 300 $\mu\mu$, as in Plate **2**, *e*, but from this region to the visible spectrum lies an almost continuous mass of strong lines, very intense in the region where the quartz mercury arc is conspicuously weak, say from the group at wave length 313 $\mu\mu$ to the group near wave length 365 $\mu\mu$.

For radiometric measurements the magnetite arc, which was operated at 6.6 amperes and about 80 volts, proved much more steady than the carbon arc, showing more small and quick fluctuations, but fewer of the large and relatively slow variations which interfered most with the readings. As a consequence the deflections obtained agreed more closely, the average variations of a single setting running between 3 and 4 %. For the magnetite arc through the quartz window the cut-off of Euphos glass amounted to 29 cm., 28 % of the total deflection. Through the ordinary glass globe the deflection was reduced to 22.4 cm., 22.5 % of the total deflection. The difference between these results shows that while there is a large amount of energy of short wave length produced by the magnetite arc, most of the ultra violet energy is of wave length greater than 300 $\mu\mu$. As compared with the quartz mercury arc used without its globe the magnetite arc gave relatively about 60 % less energy of wave length below 300 $\mu\mu$ and about 40 % more energy in the wave lengths above 300 $\mu\mu$. The candle power in the horizontal direction as measured by the method just described amounted to 760 in the run with the quartz window, and 700 in the run with the ordinary globe.

The Nernst Lamp. — Finally a series of readings was taken on the Nernst lamp. The lamp investigated was of the single glower type for 220 volts, taking 91 watts and giving a downward c. p. of 68. As the spectrum of this source runs to less than wave length 300 $\mu\mu$ and reaches that vicinity with somewhat material strength an attempt was at first made to run the Nernst glower without a globe. It proved so difficult to get steady deflections under these conditions, on account of the effect of air currents, that this measurement was

abandoned and the readings taken with the globe on, which proved reasonably easy, the precision being comparable with that obtained with the ordinary incandescent lamps. But even then the lamp proved very sensitive to small changes of voltage and only by very careful regulation of the current could consecutive series of readings be held in reasonably close agreement.

In the average the deflection due to the ultra violet in the Nernst lamp with its globe was 1.81 cm. and the percentage of energy thus cut off was 5.2. This completed the radiometric investigation of ordinary illuminants. Two others which it seemed desirable to investigate, that is the ordinary flame arc, and the arc between iron electrodes as used by Finsen were studied on the spectrograph, since their fluctuations were of a character to make their study by means of a galvanometer of so long period as that used in this investigation quite impracticable. The peculiarities of these sources will be referred to in discussion of the general results.

Sun Light. — Finally it seemed advisable to take some comparative readings on sunlight as a source of ultra violet radiations, particularly with reference to the amount of ultra violet energy with respect to the intensity of the light. Of course the solar radiation in absolute amount has been investigated with great thoroughness, but the ultra violet has received less attention than the rest of the spectrum. In general the sun radiates energy substantially like an incandescent black body at about 6000 degrees C. except in so far as its energy, particularly in the ultra violet, is cut off by the absorption of its own and the terrestrial atmosphere. It behaves then, like an enormously hot incandescent body shining through a medium that cuts off all the ultra violet of less wave length than about 295 $\mu\mu$ and greatly diminishes the shorter radiations even into the violet of the visible spectrum. One would expect therefore to find relatively little total ultra violet per unit of illumination so far as the direct light of the sun is concerned. On the other hand as Schuster [14] and others have shown, much of this cutting off of the ultra violet is due to scattering of the short waves by the molecules of the atmosphere and small bodies suspended in it. In other words, the violet and ultra violet are not wholly lost, but appear in radiation from the blue sky.

Of the energy thus radiated from the sky the maximum lies almost in the edge of the ultra violet. The arrangement of the apparatus for experiments on sunlight is shown in Figure 5. Through the

[14] Nature, XXXI, p. 97.

courtesy of the Director, this part of the work was done in the Rogers Laboratory of Physics where the conditions for getting natural light were good. In Figure 5, A is a *porte lumiére* receiving the light from the sun and forming by means of the iris diaphragm B, stopped to 3 mm. diameter, an image of the sun on the thermopile front at C, before which was placed the usual quartz cell D. The thermopile was connected with the galvanometer F, read by the telescope and scale G. By the use of the diaphragm, forming a species of "pin hole" image on the face of the thermopile, at a distance of 3 meters,

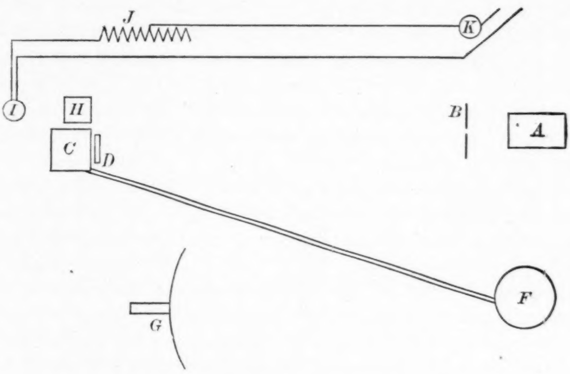

FIGURE 5. Apparatus for solar radiation.

the light and energy were cut down so as to be readable with comparative ease.

To measure the intensity of the illumination a Simmance-Abady flicker photometer H was set up close alongside the thermopile so that the solar image could be quickly moved so as to fall squarely on the photometer disc. On the other side of the photometer at I was an 80 watt tantalum lamp which was previously calibrated, in terms of the current flowing through it, against a standardized Gem lamp. From the source of supply the current was taken to this lamp through an adjustable rheostat J and a mil-amperemeter K. In measuring the light-intensity of the beam which was allowed to fall on the thermopile, it was simply shifted from the face of the thermopile to the face of the photometer and by means of the rheostat J

a flicker balance was established. The current read on K and referred to the standardization curve at once gave the c. p. of I, so that the illumination could be computed.

The mirror at A was an electrolytic nickel surface highly polished, inasmuch as nickel gives a considerably higher coefficient of reflection near the end of the solar spectrum than does silver, which is particularly weak at this point. To separate the extreme violet and ultra violet as before and on exactly the same basis, the solar readings were taken with simply the quartz cell and then with the Euphos glass and a glycerine film. The cut off of violet and ultra violet produced by the Euphos glass in the first day's readings was 16.2 % and in a second day's reading 17.9 %, both days being brilliantly clear and cold in late December at noon. The average energy therefore cut off was substantially 17 % uncorrected for the coefficient of reflection of the nickel mirror, or approximately 21 % after the correction for the variation in reflection as between the ultra violet and the visible spectrum.

This figure is somewhat large as compared with the data ordinarily quoted for the ultra violet component of the solar spectrum, but it should be noted that this comparison is not with the spectrum as a whole but with that portion of it transmitted by a quartz cell filled with distilled water which cuts off a large part of the infra red. Also the absorption of the Euphos glass extends into the violet as has been previously noted, and finally the observations were taken in cold winter weather when the aqueous vapor, which is important in the absorption of the atmosphere, is pretty well frozen out.

The observed difference of deflection in these experiments on the sun due to the cut off of the ultra violet was 2.28 cm. and the observed intensity of the illumination was equivalent to 101 foot candles. These readings show precisely what the general theory indicates, that the solar light must be regarded as received from an enormously hot and hence very efficient radiator which has been robbed by atmospheric scattering and absorption of a considerable part of its shorter wave lengths.

Record of General Results.

In these experiments the following artificial sources of light were investigated with respect to the ultra violet component of each as separated from the rest of the spectrum by a disc 2 mm. thick of Euphos glass #1:— G. E. M. lamp; tungsten lamp; Cooper Hewitt

tube; quartz lamp of the French Cooper Hewitt Company without globe; quartz lamp, American, without globe; quartz lamp, American, with globe; Graetzin mantle burner; acetylene flame; carbon electric arc through quartz window; magnetite arc through quartz window; magnetite arc with ordinary globe; Nernst glower. In addition, a study was made of sunlight with the thermopile for comparative purposes and spectrographic studies were also made of the ordinary yellow flame arc and of the arc between iron terminals such as is used for therapeutic purposes. The Euphos glass was chosen as the medium for the partition of the ultra violet from the rest of the spectrum for the reason that it cuts out and was intended to cut out by its designers all the rays of any illuminant which are under indictment as having specific harmful action on the eyes.

Broadly, the accusations of short wave lengths as injurious to the eye involve the entire ultra violet from the furthest point reached by natural or artificial illuminants up to and into the chemically active rays of the violet. If on the one hand it is the rays in the extreme ultra violet, wave length 300 $\mu\mu$ and less, which are absorbed by the cornea, that are held responsible for the ordinary phenomena of *ophthalmia electrica*, it is the rays of ultra violet of greater wave length than this, extending clear into the violet, that have been regarded by some recent investigators as producing perhaps serious lesions of the retina and of the lens. Note Schanz and Stockhausen.[15] The former class of injuries which have to do with the radiations absorbed by the cornea are wholly superficial and, according to Van Lint [16] the prognosis is generally good and the recovery rapid. Injuries to the retina and the lens, in-so-far as they take place, involve a far greater danger of permanent injury. Glass-blowers cataract is one of the typical injuries which has been ascribed to ultra violet radiations lying adjacent to the visible spectrum by Schanz and Stockhausen, Birch-Hirschfeld and others. Obviously, the temperature of melting glass (1400° C) is too low to give rise to any material amount of energy in the extreme ultra violet.

The present investigation, therefore, took account of the whole body of radiations of short wave length. So far as possible injury from the ultra violet component in any artificial light source is concerned it is obviously dependent on the amount of actual energy delivered by the source in the ultra violet region and not upon the

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[15] Ztschr. f. Augenheilk., Mai, 1910.

[16] Accidents oculaires provoqué's par l'électricité, p. 100.

percentage relation of this energy to the whole input. It is quite clear that in order to do any injury to the eye a certain amount of energy must be spent upon it and must be delivered at a rate in excess of the power of the eye to repair damages. One receives injury from excessive exposure to ultra violet rays just as he receives it by excessive exposure to heat rays. In either case the delivery of energy at a very high rate for a considerable time does damage.

TABLE I.

Source	*Input*	*Total u. v.*	*u. v. per watt*
100 Watt G. E. M.	100	215	2.15×10^{-7}
Glass Mercury Lamp (½ length taken)	96	577	6.02×10^{-7}
Nernst (with globe)	91	640	7.03×10^{-7}
100 Watt Tungsten	103	670	6.50×10^{-7}
New Quartz Lamp (with Alba globe)	460	1305	2.84×10^{-7}
Old Quartz Lamp (without globe)	260	5920	22.8×10^{-7}
Magnetite Arc (with globe)	530	7900	14.9×10^{-7}
Magnetite Arc (no globe)	530	10240	19.7×10^{-7}
New Quartz lamp (without globe)	350	11350	32.5×10^{-7}
Carbon Arc (quartz window)	495	26200	52.9×10^{-7}

At a moderate rate and for a moderate time the constructive forces of the organism are not over balanced by the destructive forces of the radiations. Hence the first application of the data obtained from the sources investigated was to determine the actual rate at which ultra violet energy was delivered by them. Table I shows for all the electric sources of light, of which the input could be readily measured, the gross input in watts at the lamp terminals, the total ultra violet radiation in ergs per second per square cm. at the standard distance of half a meter and finally, this ultra violet output in terms of ergs square cm. per second per watt input. This last column is proportional to the efficiency of the source as a producer of ultra violet radiations in terms of the gross input.

In Table I the highest ultra violet output per watt of input is reached by the carbon arc operated in the manner already described. The next highest figure is given by the quartz lamp operated without its globe, a condition of relatively low luminous efficiency which would only be found in cases where the arc was being used for bactericidal purposes or other special tasks where ultra violet radiations are

important. The very high ultra violet output reached by the carbon arc is as has already been pointed out largely due to the very intensive cyanogen bands about in the middle of the ultra violet spectrum and the output of wave length below 300 $\mu\mu$ is materially less than it is in the quartz lamp operated without its globe.

At the other end of the list stand the G. E. M. lamp and the ordinary Cooper-Hewitt tube, the former showing a very low ultra violet output by reason of its relatively low temperature and the latter by reason of the fact that the extreme ultra violet is entirely cut off by the tube, and the middle ultra violet being very weak in the mercury spectrum, the main body of the energy is of wave length greater than 365 $\mu\mu$. In fact since the spectrum of the G. E. M. lamp runs down nearly to wave length 300 $\mu\mu$, and is strong only between say 360 and the visible, the energy distribution of the spectra of these two illuminants is singularly similar, considering their wide difference in character.

The Nernst and tungsten lamps produce rather more total ultra violet than the Cooper-Hewitt tube, most of the output being toward the visible spectrum. The Nernst lamp operated without its globe gives a spectrum relatively stronger in the further ultra violet, reaching wave length 300 $\mu\mu$ with a considerable degree of strength and stretching beyond it. All the lamps running with glass globes show a weak spectrum in that region. For this reason the quartz lamp with its regular diffusing globe shows an ultra violet output per watt almost as low as the G. E. M. lamp, the cut off of the globe in the ultra violet region being very striking. The magnetite arc both with and without its globe gives a considerable ultra violet output. The globe cuts off much less ultra violet than in the case of the quartz lamp, the latter being relatively rich in the rays which the glass most effectively absorbs.

Table II shows the percentage of energy cut off by the Euphos glass in each of the illuminants investigated as compared with the total energy which was transmitted by the quartz water cell, and also the relative horizontal c. p. of the sources dealt with. The percentage ratios of ultra violet are therefore numerically higher than they would be in the case of admitting the whole infra red to the thermopile. The relative composition of the various sources, however, is well expressed by the data.

TABLE II.

Source	% of energy cut off by euphos	Candle power (horizontal)
100 Watt G. E. M.	2.6	39.25
Acetylene Flame	4.5	27.35
Nernst (with globe)	5.2	68.0
Tungsten (100 wt.)	6.0	79.4
Graetzin Gas Lamp	8.4	75.0
Sunlight	21.0	272.(equivalent)
Magnetite Arc (glass globe)	22.5	700.0
Magnetite Arc (quartz window)	28.0	760.0
Carbon Arc (quartz window)	30.0	720.0
Mercury Arc (glass)	41.7	100.
New Quartz Lamp (with Alba globe)	42.5	820.
Old Quartz Lamp (no globe)	55.7	415.
New Quartz Lamp (no globe)	65.1	348.

It will be noted that the smallest percentage of ultra violet is shown again by the G. E. M. lamp, with the acetylene flame standing second. The Welsbach mantle of the Graetzin lamp runs materially higher than any of the electric incandescent lamps in spite of the fact that this lamp was tested with its globe on. Next higher than the Graetzin lamp, and approximating the arc lamps, comes sunlight, standing between the incandescent sources which give a continuous spectrum and the arcs of various sorts which give highly selective radiation. At the other end of the list is the quartz lamp worked intensively without its globe. These ratings of the various illuminants are instructive as showing the distribution of the energy as between ultra violet and the remainder of the spectrum, but they are not significant as regards the extremely practical matter of illumination. If the ultra violet component of artificial light involves any risk of injury to the eyes the one important thing to find out in comparing sources of light is how much ultra violet they deliver for a given illumination. In other words if one desires to light a room, say to an intensity of five foot candles, with what illuminant can he obtain this intensity while receiving the minimum amount of ultra violet radiation? It is not of the slightest practical consequence from the standpoint of good and safe illumination whether a given light source produces much or little ultra violet per watt, provided it produces an insignificant amount per foot candle, hence the luminous efficiency

of the source is in the last resort the thing which determines the presence or absence of ultra violet radiation in material amount. In other words the more efficiently the energy supplied to the illuminant is transformed into light the less important does the ultra violet radiation become in considering the source as a practical illuminant.

TABLE III.

Source	*Deflections due to u. v. in cm.*	*Ultra violet ergs per sec. per cm² per foot candle*
Quartz Arc (Alba globe)	3.70	4.3
Graetzin Gas Lamp	.92	11.7
G. E. M. Lamp	.61	14.8
Cooper-Hewitt (glass)	1.64	15.5
Sunlight (direct)	2.28	16.1
Acetylene Flame	.52	18.4
Tungsten Lamp	1.90	22.7
Nernst Lamp (globe)	1.81	25.5
Magnetite (glass)	22.40	30.3
Magnetite (quartz)	29.00	36.3
Old Quartz Lamp (bare)	16.77	38.3
New Quartz Lamp (bare)	32.10	87.6
Carbon Arc (quartz)	74.00	91.0

Table III assembles the commercial light sources tested, with respect to the ultra violet energy accompanying a given illumination. The first column of the table gives merely for the purpose of record the actual deflections found to be due to the ultra violet energy, and column two the total ultra violet radiation in ergs per second per square cm. per foot-candle of illumination. At the head of the list stands the quartz mercury arc with its diffusing globe. Of the commercial illuminants tested this gives by all odds the smallest proportion of ultra violet per foot candle. As the previous tables show, the ultra violet energy of this source so equipped is small from any point of view. Its unique position, however, is due largely to the fact that the light-giving radiation, which lies practically at the very peak of the luminosity curve for vision, is produced at enormous efficiency, according to Buisson and Fabry [17] not less than 55 candles per watt for the green line at wave length 546 which supplies nearly two thirds

[17] Comptes Rendus, Vol. 153, p. 254.

of the total light and at almost as high efficiency for the pair of yellow lines which supply nearly all the rest. Next in the list, a rather bad second, comes the Graetzin gas lamp, its position again being due to the somewhat selective radiation that gives it a very high luminous efficiency. Third, comes the G. E. M. lamp which, from its relatively low temperature, gives a small absolute amount of ultra violet radiation, although its luminous efficiency is not great.

At the other end of the line comes the special enclosed arc with 91 ergs per second per square cm. per foot candle, and next to it the quartz lamp without its globe. Of course the quartz lamp without its globe is never used for illuminating purposes, but only for such work as sterilization of water and the like in which the ultra violet rays are the things sought. Operated for this purpose it undoubtedly is the most efficient powerful source of extreme ultra violet. To test this feature of the matter energy measurements were taken on the two quartz lamps without their globes and on the magnetite lamp free from its globe while using as a screen instead of the Euphos glass a disc of the very light crown glass previously referred to, which practically effects a separation at wave length 300 $\mu\mu$ absorbing substantially all the energy below this point and transmitting at almost full intensity the rest. The result of this test, measuring the extreme ultra violet and reducing it to the mean spherical output of ultra violet, showed for the extreme ultra violet efficiency of the new quartz lamp 4.07 % and for the efficiency of the old quartz lamp 3.14 %. A similar measurement of the magnetite arc showed an extreme ultra violet efficiency of 1.13 %. These figures may be properly compared with the tests for the ultra violet efficiency of the quartz lamps made by Fabry and Buisson.[18] In this case two mercury lamps showed respectively extreme ultra violet efficiencies of 6.4 and 4.7 %, the ultra violet separation being effected by the screens used by Fabry and Buisson at wave length 320 $\mu\mu$. The values obtained by the French investigators and in this study therefore check each other closely, showing that in the quartz mercury lamp 4 to 5 % of the total input is returned in the form of extreme ultra violet radiation when the lamps are operated, as they are for sterilization purposes, without their globes. The lighting power of the lamp falls off very greatly in this condition.

When operated with the globe the total proportion of ultra violet becomes both absolutely small and extremely small relatively to the

[18] Comptes Rendus, Vol. 153, p. 93.

light given. In this connection the position of sunlight in Table III is not without importance. On the face of the returns it has a less amount of ultra violet with respect to the illumination than most of the artificial illuminants. This is due to the very high temperature of the source, which insures high luminous efficiency, in connection with strong ultra violet absorption in the atmosphere. Unfortunately one can apply Planck's law to very few practical sources of light. The sun is ruled out by the very erratic and highly selective absorption which produces the Frauenhofer lines and also by an unknown absorption of the extreme ultra violet which may take place in the earth's atmosphere or near the solar surface or in both places. Incandescent lamps involve absorption by their globes and also in the case of more recent ones a certain amount of selective radiation. The whole tribe of arcs which yield in a greater or less degree discontinuous spectra, for which Planck's law does not hold, are also thereby eliminated, so that this otherwise very useful guide to the distribution of radiation ceases to have exact significance.

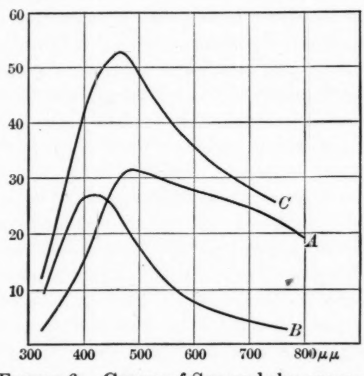

FIGURE 6. Curves of Sun and sky energy.

The ultra violet component of sunlight has been considerably disputed. It has been held by some investigators like Dr. Voege[19] that sunlight contains more ultra violet than the arc light, while Schanz and Stockhausen[20] take the opposite view. In a sense both are right and both wrong. Sunlight undoubtedly contains only a very modest proportion of ultra violet per foot candle of illumination when one considers direct sunlight alone. If, however, one considers the total daylight effect, including skylight under favorable circumstances, the situation takes on a totally different aspect. The light diffused by the blue sky is mainly violet and ultra violet, being substantially that light of which the direct sunbeam is robbed by scattering. Figure 6 shows in curve

[19] The Illuminating Engineer, Lond., Vol. II, p. 205.
[20] The Illuminating Engineer, Lond., Vol. I, p. 1049.

A the distribution of energy in the directly received solar light. Curve B shows the distribution of energy in the diffused light of the blue sky when the total of this diffused energy equals 20 % of the total directly received solar energy, a not uncommon proportion. It will be noted that the maximum for this curve is in the far violet near the edge of the ultra violet. Curve C is the summation of A and B and it will be seen at once that the proportion of ultra violet is something like three times as great as in the case of the direct solar rays. This proportion would raise the ultra violet activity of daylight to a point higher per foot candle than that reached by any ordinary artificial illuminant.

Weisner [21] in photographic observations of light received on horizontal surfaces states for example, "For solar altitudes less than 19 degrees the chemical intensity of the sunlight as compared with diffused daylight is negligible, with increasing solar altitude it gains in comparison with the diffused daylight. * * * Since the intensity of the direct beam may reach twice that of the diffused, the total combined chemical effect may be three-fold that of the diffused light."

Daylight, therefore, varies very greatly in ultra violet energy, ranging from the low value given in Table III for direct sunlight to values which would exceed almost all artificial light sources. The chief claim of sunlight to serious consideration from the standpoint of ultra violet energy, however, lies in the very large amount of energy which the sun delivers. There is considerable doubt as to the exact amount of solar radiation outside of the atmosphere, but that which gets through the atmosphere is pretty well determined and its amount, from the data given by Abbott [22] amounts practically, under favorable conditions, to not less than 1 kw. per square meter, which is 0.1 watt per square cm. If one assumes that only 10 % of this is in the ultra violet region, an amount which may be exceeded at times, the total ultra violet radiation rises to 10^5 ergs per second per square cm., several times that given by the most powerful artificial sources of ultra violet at even a distance of so short as half a meter.

Considering this very large flux of ultra violet energy it is small wonder that troubles from sunburn and snow-blindness are not infrequent. Did we not habitually shield our eyes by interposing the rim of the hat or the brow and by systematically looking away from the direct sunlight ocular troubles would be common and severe.

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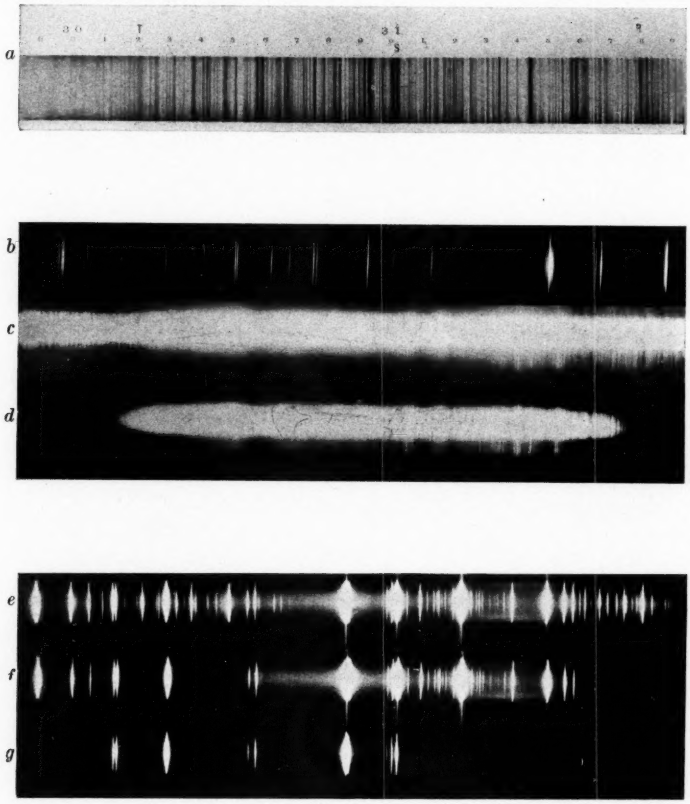
[21] Denkschriften Wien. Akad., Vol. 64, 1897.
[22] "The Sun", Chapter VII.

Snow is a good reflector of ultra violet radiations, at least throughout the limits of the solar spectrum. At two meters distance a square meter of snow surface may reflect to the eye as much as 10^4 ergs per second per square cm. If even one tenth of this is in the ultra violet then a square meter of snow in the field of vision at two meters distance would deliver about 1000 ergs per second of ultra violet per square cm., which is in excess of the greatest amount which would be given at this distance by any of the artificial sources of light here investigated.

Fortunately the sun is weak in the extreme ultra violet, but the very large amount of radiation which can be reflected to the eye from a snow covered surface is quite sufficient to account for all the phenomena observed, even although the ultra violet per foot-candle in the sunbeam is rather exceptionally low.

Two sources of light, not here measured for reasons already stated, should not be forgotten. One of these is the iron arc used for therapeutic purposes, of which the spectrum is shown along side of the mercury spectrum in Plate, **2**, *g*. It will be observed that it is enormously rich in lines, even to the extreme ultra violet, and as the light giving power between iron terminals is not high, this source would stand very near the bottom of Table III. The yellow calcium fluoride arc, of which the spectrum is similarly shown in Plate **2**, *i*, would unquestionably stand near the quartz arc at the head of the list, owing both to its very high luminous efficiency and to the comparatively weak lines in the extreme ultra violet.

In conclusion it may be confidently stated that no commercial illuminant radiates for any ordinary working value of the illumination enough ultra violet energy to be at all harmful, provided one exercises ordinary discretion is keeping unpleasantly bright visible light out of the eyes.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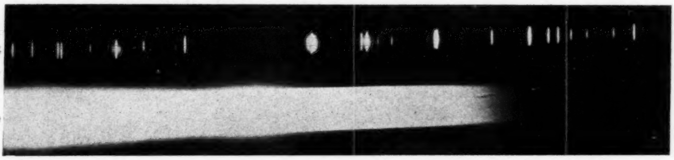

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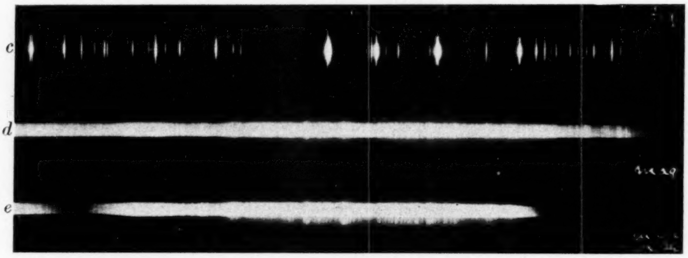

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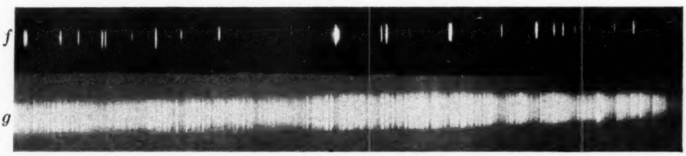

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